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THE CLASSIFICATION OF CLIMATES: I.*

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SYNOPSIS.

Need of a Classification of Climates.—Relation of Continental and Ocean Areas to Temperature: reasons for the slow change in the temperature of ocean waters.—Marine or Oceanic Climate.—Continental Climate.—Desert Climate.—Coast or Littoral Climate.—Monsoon Climate.—Mountain and Plateau Climate.—Mountains as Climatic Divides.

Need of a Classification of Climates.—A broad division of the earth's surface into zones is necessary as a first step in any systematic study of climate, but it is not satisfactory when a more detailed discussion is undertaken. The reaction of the physical features of the earth's surface upon the atmosphere complicates the climatic conditions found in each of the zones, and makes further subdivision desirable. Under the control of these different physical conditions the climatic elements unite to produce certain fairly distinct types of climate, and these may be classified in various ways. The usual method is to separate the *continental* (near sea-level) and the *marine.* An extreme variety of the continental is the *desert;* a modified form, the *littoral;* while altitude

* It is the object of this article to give a brief summary of the general climatic types which result from the control of land and water, and of altitude, over the more important elements of climate.

The following references have been consulted, in addition to those given in later foot-notes:

W. M. Davis: Elementary Meteorology, Boston, 1894, 335-344.

J. Hann: Handbook of Climatology. Translated by R. DeC. Ward. London and New York, 1903, 128-180, 222-374.

W. Köppen: Klimalehre, Leipzig, 1899, 93-104.

W. J. van Bebber: Hygienische Meteorologie, Stuttgart, 1895, 247-254.

is so important a control that *mountain* and *plateau* climates are further grouped by themselves.

Relation of Continental and Ocean Areas to Temperature.—Land and water differ greatly in their behaviour regarding absorption and radiation. The former warms and cools readily, and to a considerable degree; the latter, slowly and but little. (1) Of the insolation which falls upon the ocean a good deal is at once reflected, and is therefore not available for warming the water. Land surfaces, on the other hand, are poor reflectors; but little insolation is lost in that way; hence more energy is available for raising their temperature. (2) Most of the insolation which enters the water is transmitted to some depth, and, therefore, is not effectively applied to warming the surface. Land is opaque and does not allow the incident insolation to pass beyond a comparatively thin surface stratum; hence this surface can be well warmed. (3) The evaporation of water requires a large amount of energy, which changes the state of the water without raising its temperature (latent heat). Land, although often moist, is itself non-volatile; therefore the loss of energy in the process of evaporation is usually very slight. (4) Water is more difficult to warm than any other natural substance, while land is warmed easily and quickly. If equal amounts of heat are received by equal areas of land and water, the former warms about twice as much as the latter. (5) The mobility of water keeps the warmer and the colder portions well mixed, and therefore greatly retards the process of warming any one portion of the surface. Land cannot thus equalize its temperature. (6) The cloudiness over the oceans is usually greater than over the lands, and this operates to shade the former more than the latter, reducing the energy available for warming the water surface. For these various reasons, ocean surfaces can warm but little during the day, or in summer, and can cool but little during the night or in winter. They, and the air over them, are therefore conservative as regards their temperatures. Land areas, and the air over the lands, on the other hand, warm and cool readily.

Marine or Oceanic Climate.—Conservatism in its temperature conditions is the most distinctive feature of a marine climate. The results of the "Challenger" Expedition show that the diurnal range of air temperature over the ocean between latitudes 0° and 40° averages only 2° or 3°. Further, the slow changes in temperature of the ocean waters involve a retardation in the times of occurrence of the maxima and minima, and a marine climate, there-

fore, has characteristically a cold spring and a warm autumn, the seasonal changes of temperature being but slight. The surface waters of oceans and lakes average somewhat warmer than the air over them, and for this reason all considerable bodies of water which remain unfrozen in winter become sources of warmth for the adjacent lands during the colder months. Characteristic, also, of marine climates is a prevailingly higher relative humidity, a larger amount of cloudiness, and a heavier rainfall than is found over continental interiors. All of these features have their explanation in the abundant evaporation from the ocean surfaces. In the middle latitudes, again, there is this contrast between the oceans and the continental interiors, that the former have distinctly rainy winters, while over the latter the colder months have a minimum of precipitation. Ocean air is cleaner and purer than land air, and ocean air is, on the whole, in more active motion, because friction of air on water is less than friction of air on land.

It is obvious that an equable, damp, and cloudy climate such as that which is, on the whole, typical of the oceans and of their leeward coasts must affect vegetation in a way quite different from that noted in a hotter and drier climate, with greater variations of temperature. Thus Schindler* has shown that wheat contains less protein in a marine climate, and hence more meat, leguminous plants, and other nitrogenous foods are necessarily eaten. An interior climate, like that of Southern Russia and Hungary, produces wheat which is richer in protein: the need of other nitrogenous foods is consequently decreased. The proportion of starch is decreased, and that of gluten is increased, in a hot, dry climate. The size of the crop is also affected by the climate.

Continental Climate.—Marine climate is equable; continental is severe. The annual temperature ranges increase, as a whole, with increasing distance from the oceans;† the regular diurnal ranges are also large, reaching 35° or 40°, and even more, in the arid continental interiors. The warmest and coldest months are usually January and July, the times of maximum and minimum temperatures being less retarded than in the case of marine climates. April is usually warmer than October, unless spring warming is delayed by the melting of a snow-cover. In the latter case, the snow-covered land surface temporarily takes on the charac-

* F. Schindler: *Der Weizen in seinen Beziehungen zum Klima*, Berlin, 1893.

† See chart of equal annual ranges of temperature, Bartholomew's Atlas of Meteorology, Pl. 2.

teristics of a water surface, and has a retarded spring. The greater seasonal contrasts in temperature over the continents than over the oceans are furthered by the less cloudiness over the former. The clearer continental skies of high latitudes favour a lowering of the winter, but a slight rise of the summer temperatures, while in lower latitudes the clearer summer skies favour a higher mean annual temperature. Diurnal and annual changes of nearly all the elements of climate are greater over continents than over oceans; and this holds true of irregular as well as of regular variations. The contrast between marine and continental climates in the matter of the annual march of temperature is shown in the accompanying figure (Fig. 1). In low latitudes the curve for Funchal, on the island of Madeira (M), represents the marine type, and that for Bagdad, in Asia Minor (Bd), the continental. For higher latitudes, the curves for Valentia (V), a coast station in the southwest of Ireland, and for Nertschinsk (N), in eastern Siberia, are representatives of the two types.

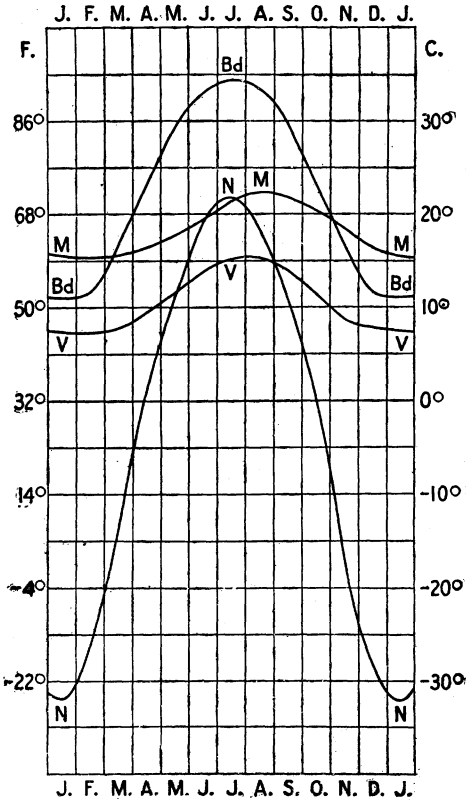

FIG. 1 (AFTER ANGOT).
ANNUAL VARIATION OF TEMPERATURE.

Owing to the distance from the chief source of supply of water-vapour—the oceans—the air over the larger land areas is naturally drier and dustier than that over the oceans. Yet even in the arid continental interiors in summer the absolute vapour content is surprisingly large, although the air is still far from being saturated. In the hottest months the percentages of relative humidity may reach 20% or 30%. At the low temperatures which prevail in the winter of the higher latitudes the absolute humidity is very

low, but, owing to the cold, the air is often damp. Cloudiness, as a rule, decreases inland, reaching its minimum in deserts. And with this lower relative humidity, more abundant sunshine and higher temperature, the evaporating power of a continental climate is much greater than that of the more humid, cloudier, and cooler marine climate. Actual evaporation is, however, under these conditions, usually much less than the possible evaporation which would take place were there enough water present to be evaporated. Both amount and frequency of rainfall, as a rule, decrease inland, but the conditions are very largely controlled by local topography and by the prevailing winds. The decreased frequency of rainfall on the lowlands is especially marked in winter. Winds average somewhat lower in velocity, and calms are more frequent, over continents than over oceans. The seasonal changes of pressure over the former give rise to systems of inflowing and outflowing, so-called continental, winds, sometimes so well developed as to become true monsoons. Usually, however, the changes in direction and the development are not very marked.

In winter, clear, crisp days, followed by cold, calm nights, and interrupted from time to time by spells of cloudy, windy weather, with or without light precipitation; in summer, clear, calm nights, followed by hot days with increasing wind velocity and heavy clouds towards noon, and often by thunderstorms in the later afternoon. These are typical weather conditions of continental interiors in the higher latitudes; and they are of much interest to man. The extreme temperature changes which occur over the continents are the more easily borne because of the dryness of the air; because the minimum temperatures of winter occur when there is little or no wind, and because during the warmer hours of the summer there is the most air movement.

Desert Climate.—An extreme type of continental climate may be found in deserts. It is a curious fact that desert and marine climates—the two extremes of the climatic scale—resemble one another in some respects. Desert air, albeit often dusty by day, is notably free from micro-organisms; the purity of ocean air is well known. Again, deserts and oceans alike have high wind velocities. The large diurnal temperature ranges of inland regions, which are most marked where there is little or no vegetation, give rise to active convectional currents during the warmer hours of the day. Hence high winds, disagreeable because of the dust and sand which they carry, are common by day, while the nights are apt to be calm and relatively cool. Travelling by day is un-

pleasant under such conditions. Diurnal cumulus clouds, often absent because of the excessive dryness of the air, are thus replaced by clouds of blowing dust and sand. This sand, often carried afar, may find a resting-place on the moister lands to leeward. Thus beds of loess are formed. Indeed, many geological phenomena, and special physiographic types of varied kinds, are associated with the peculiar conditions of desert climate.* The excessive diurnal ranges of temperature cause rocks to split and break up. Wind-driven sand erodes and polishes the rocks. When the separate fragments become small enough they, in their turn, are transported by the winds and further eroded by friction during their journey. The ground is often swept clean by the winds. Curious conditions of drainage result from the deficiency in rainfall. Rivers "wither" away, or end in sinks or brackish lakes. Desert plants protect themselves against the attacks of animals by means of thorns, and against evaporation by means of hard surfaces and an absence of leaves. The life of man in the desert is likewise strikingly controlled by the climatic peculiarities of strong sunshine, of heat and of dust.

Coast or Littoral Climate.—Between the pure marine and the pure continental types the coasts furnish almost every grade of transition. Hence coast or littoral climates may well be placed in a group by themselves. Prevailing winds are here important controls. When these blow from the ocean, as on the western coasts of the temperate zones, the climates are more marine in character; but when they are offshore, as on the eastern coasts of these same zones, a somewhat modified type of continental climate prevails, even up to the immediate sea-coast. Hence the former have a much smaller range of temperature; their summers are more moderate and their winters milder; extreme temperatures are very rare; the air is damp; there is much cloud. All these marine features diminish with increasing distance from the ocean especially when there are mountain ranges near the coast, as is the case in the western United States and in Scandinavia. In the tropics, windward coasts are usually well supplied with rainfall, and the temperatures are modified by sea breezes. Leeward coasts in the trade-wind belts offer special conditions. Here the deserts often reach the sea, as on the western coasts of South America, Africa, and Australia. Cold ocean currents, with prevailing winds along rather than on-shore, are here hostile to rainfall, although the lower air is often damp, and fog and cloud are not uncommon.

* See, for example, W. M. Davis: Physical Geography, Boston, 1899, 297–324.

Monsoon Climate.—Exceptions to the general rule of rainier eastern coasts in trade-wind latitudes are found in the monsoon regions, as in India, for example, where the western coast of the peninsula is abundantly watered by the wet southwest monsoon. As monsoons often sweep over large districts, not only coast but interior, a separate group of monsoon climates is desirable. In India there are really three seasons—one cold, during the winter monsoon; one hot, in the transition season; and one wet, during the summer monsoon. Little precipitation occurs in winter, and that chiefly in the northern provinces. The high temperatures of the transition periods are most oppressive when the air is most damp. In India this is the case in the autumn. In low latitudes, monsoon and non-monsoon climates differ but little, for summer monsoons and regular trade winds both give rains, and wind direction has slight effect upon temperature.

The winter monsoon is offshore and the summer monsoon onshore under typical conditions, as in India. But exceptional cases are found where the opposite is true. Thus, on the northwestern coast of Japan, the northeastern coasts of Formosa and of the Philippines, and the eastern coasts of the southern Deccan and of Ceylon, the prevailing offshore winter dry monsoon becomes an onshore rainy wind. Many complicated cases of this kind are not easily co-ordinated. In higher latitudes the seasonal changes of the winds, although not truly monsoonal, involve differences in temperature and in other climatic elements. The eastern coast of the United States has prevailing cold, dry, clear winds from the continental interior in winter, while the prevailing winds of summer are southwest, and hence warm and often moist. The only well-developed monsoons on the coast of the continents of higher latitudes are those of eastern Asia. These are offshore during the winter, giving dry, clear, and cold weather; while the onshore movement in summer gives cool, damp, and cloudy weather. Without these seasonal winds the winters would have the maximum amount of rain and cloud.

Mountain and Plateau Climate.—Both by reason of their actual height and because of their obstructive effects, mountains influence climate similarly in all the zones. Hence mountain and plateau climates are placed in a group by themselves, as distinguished from those of lowlands. The former, as contrasted with the latter, are characterized by a decrease in pressure, temperature, and absolute humidity; an increased intensity of insolation and radiation; larger ranges in soil temperature; usually a greater frequency of, and up to a certain altitude more, precipitation.

At an altitude of 16,000 ft., more or less, pressure is reduced to about one-half of its sea-level value. The highest human habitations are found under these conditions. While the pressures and the pressure changes at sea-level have no marked effect upon man, the physiological effects of the decreased pressure aloft (faintness, nausea, headache, weakness) are experienced by a majority of people at altitudes above 12,000 to 15,000 ft. The symptoms, and the height at which they appear, vary much in different cases,

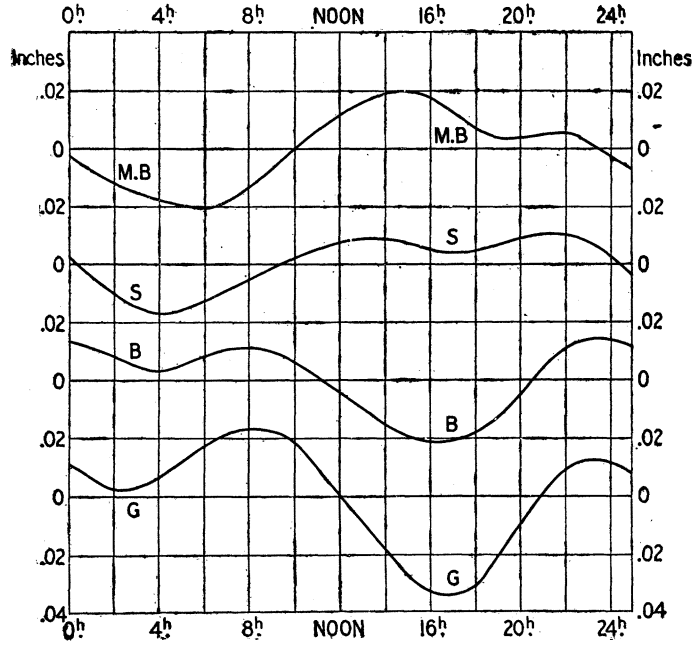

FIG. 2 (AFTER ANGOT).
DIURNAL VARIATION OF PRESSURE.

and depend upon the physical condition, the weather, bodily exertion, and so on. The greatest altitudes attained by man were reached by balloon, and in such cases a supply of oxygen is usually taken up by the aeronaut. Man endures the rapid pressure changes during balloon ascents with difficulty, and often only with considerable suffering. The eagle and the condor, however, suffer no inconvenience during their high flights.

It has been suggested by Jourdanet that mountain and plateau climates be divided into groups, *climats de montagne,* below 6,500 feet, and *climats d'altitude,* above that height. The former are beneficial because of the stimulating quality of their clean, cool

air; the latter may be injurious because of the low pressure. The variations in pressure, as well as the actual pressures, diminish aloft. On high mountains and plateaux the pressure is lower in winter than in summer, owing to the fact that the atmosphere is compressed to lower levels in the winter and is expanded upwards in summer. The morning minimum pressure on mountains is usually the primary minimum, the afternoon minimum being less marked and coming later than on lowlands. Figure 2 shows the diurnal variation of pressure at Geneva (408 meters, G), Berne (573 meters, B), on the Säntis (2,467 meters, S), and on the summit of Mont Blanc (4,811 meters, MB), and illustrates well the general characteristics of the curves found at different altitudes. Local topography, however, is an important controlling influence, and modifies such curves very much.

The intensity of insolation and of radiation both increase aloft in the cleaner, purer, drier, and thinner air of mountain climates. The great intensity of the sun's rays attracts the attention of mountain-climbers at great altitudes. The excess of surface temperature over air temperature also increases aloft, and is a favourable element in plant growth. There is likewise an increase in the range of surface temperature, although this is much influenced by exposure. The vertical decrease of temperature, which is also much affected by local conditions, is especially rapid during the warmer months and hours; mountains are then cooler than lowlands. The inversions of temperature characteristic of the colder months, and of the night, give mountains the advantage of higher temperature then—a fact of importance in connection with the use of mountains as winter resorts. At such times the cold air flows down the mountain sides and collects in the valleys below, being replaced by warmer air aloft. Hence diurnal and annual ranges of temperature on the mountain tops of middle and higher latitudes are lessened, and the climate in this respect resembles a marine condition, but topography and the conditions of local clouds and winds are here important controls. The times of occurrence of the maximum and minimum are also much influenced by local conditions. Fig. 3 shows the diurnal march of temperature for Paris (solid) and the Eiffel Tower (broken) in January and July. It will be noted that the times of maximum and minimum are retarded on the Eiffel Tower, and that the range is less than at the earth's surface. These are characteristics of mountain climates. Elevated enclosed valleys, with strong sunshine, often resemble continental conditions of large temperature range, and plateaux,

as compared with mountains at the same altitude, have relatively higher temperatures and larger temperature ranges. Altitude tempers the heat of the low latitudes. High mountain peaks, even on the equator, can remain snow-covered the year around; the plateau of southern India at 6,000 to 7,000 ft. above sea-level always has moderate mean temperatures, and from the dense

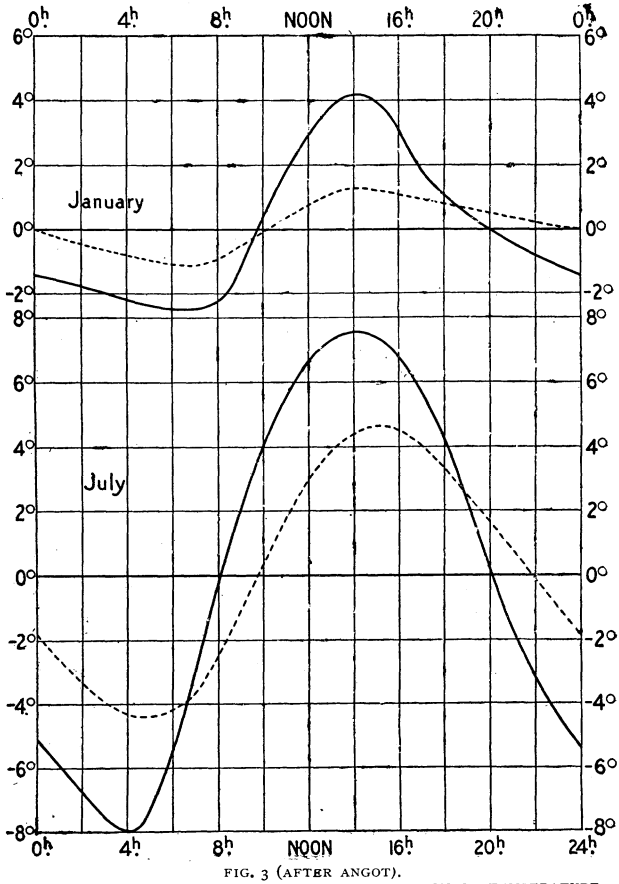

FIG. 3 (AFTER ANGOT).
INFLUENCE OF ALTITUDE ON THE DIURNAL VARIATION OF TEMPERATURE.

jungle of the tropical lowland to the snowy mountain-top successive zones of vegetation are encountered.

Nine-tenths of the water vapour in the atmosphere are below 21,000 feet. Hence mountains are important vapour barriers, and one side may be damp while the other is dry. Curiously mistaken ideas of distance often result from the remarkable clearness and dryness of the air on high mountains. No general law governs

the variations of relative humidity with altitude, but on the mountains of Europe the winter is the driest season, and the summer the dampest. At well-exposed stations there is a rapid increase in the vapour content soon after noon, especially in summer. The same is true of cloudiness, which is often greater on mountains than at lower levels, and is usually at a maximum in summer, while the opposite is true of the lowlands in the temperate latitudes. One of the great advantages of the higher Alpine valleys in winter is their small amount of cloud. This, combined with their low wind velocity and strong insolation, makes them desirable winter health resorts. Latitude, altitude, topography, and winds are determining factors in controlling the cloudiness on mountains. In intermediate latitudes there is a seasonal migration of the level of maximum cloudiness and of maximum relative humidity from the lowlands in winter to higher altitudes in the warmer months, in association with the diurnal convectional movements of the warmer season. Frequent rapid local changes also occur. In the rare, often dry, air of mountains and plateaux evaporation is rapid, the skin dries and cracks, and thirst is increased.

Rainfall usually increases with increasing altitude up to a certain point, beyond which, owing to the loss of water vapour, this increase stops. The zone of maximum rainfall averages about 6,000 to 7,000 feet in altitude, more or less, in intermediate latitudes, being lower in winter and higher in summer. Mountains usually have a rainy and a drier side; the contrast between the two is greatest when a prevailing damp wind crosses the mountain, or when one slope faces seaward and the other landward. When the prevailing winds differ little in dampness this contrast is lessened, and there may then be a very close correspondence between the rainfall and the topographic map of a region. Mountains often provoke rainfall, and local "islands," or, better, "lakes," of heavier precipitation result. Such are found on the mountains of the Sahara, and of other deserts. This local precipitation favours the growth of vegetation; small streams and oases are found, and temporary camps, or more permanent settlements, of the nomadic tribes of the desert, are there established. Well-marked zones of vegetation are noted under such conditions, as in the transition from the dry Californian lowlands up through the deciduous and then the coniferous forests of the Sierra Nevada to the snows on the summits. Similarly, the high plateaux of southern Utah and of Arizona are high enough to receive fairly abundant rainfall, while the lowlands are arid.

Mountains resemble marine climates in having higher wind velocities than continental lowlands; mountain summits have a nocturnal maximum of wind velocity, while plateaux usually have a diurnal maximum. Mountains both modify the general, and give rise to local, winds. Among the latter the well-known mountain and valley winds are often of considerable hygienic importance in their control of the diurnal period of humidity, cloudiness, and rainfall, the ascending wind of daytime tending to give clouds and rain aloft, while the opposite conditions prevail at night. The high temperature and dryness of the *foehn,* which is of immense benefit to man by reason of its melting and evaporating powers, although often enervating and depressing, result from the fact of a descent of the air from a mountain slope or summit. The bora, with its cold gusts, is a wind in whose development a mountain or plateau is essential. And the mistral of Southern France owes some of its cold to radiation over the interior plateaux.

Mountains as Climatic Divides.—Very different conditions of temperature, pressure, and humidity may be found on the opposite sides of a well-defined mountain range, because such a range interferes with the free horizontal interchange of the lower air. Mountain ranges which trend east and west, like the Alps and the Himalayas, separate more severe from less severe climates; those which follow a coast-line, as in the case of California, Scandinavia, or eastern Siberia, separate marine from continental. Large differences of pressure on the two sides may be equalized by a flow of air across the mountain, as in the foehn.

AMONG THE MOUNTAINS OF SHEN-SI.

BY

BAILEY WILLIS.

In the province of the Western Passes, Shen-si, among the outliers of the Tibetan Mountains, six hundred miles southwest of Peking, spreads a rich valley. The Wei River flows through it from west to east, and the Huang-ho, entering it from the north, turns sharply eastward and leaves it by a cañon which leads to the great plains. In extent this valley of the Wei is not unlike that of the Mohawk in northern New York, or that of the upper Danube in southern Germany. It is a wide and fertile plain,